Unclassified
SECURITY CLASSIFICATION OF THIS PAGE

REPORT DOCUMENTATION PAGE

DTIC FILE COPY

AD-A211 357

DTIC ELECTE AUG 16 1989 S D D

1b. RESTRICTIVE MARKINGS	
2b. DECLASSIFICATION / DOWNGRADING SCHEDULE	3. DISTRIBUTION / AVAILABILITY OF REPORT Approved for public release; Distribution unlimited.
4. PERFORMING ORGANIZATION REPORT NUMBER(S) GL-TR-89-0191	5. MONITORING ORGANIZATION REPORT NUMBER(S)
6a. NAME OF PERFORMING ORGANIZATION Geophysics Laboratory 6b. OFFICE SYMBOL (If applicable) LIU	7a. NAME OF MONITORING ORGANIZATION
6c. ADDRESS (City, State, and ZIP Code) Hanscom AFB Massachusetts 01731-5000	7b. ADDRESS (City, State, and ZIP Code)
8a. NAME OF FUNDING / SPONSORING ORGANIZATION 8b. OFFICE SYMBOL (If applicable)	9. PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER
8c. ADDRESS (City, State, and ZIP Code)	10. SOURCE OF FUNDING NUMBERS

PROGRAM ELEMENT NO.	PROJECT NO.	TASK NO.	WORK UNIT ACCESSION NO.
630220C	S321	06	03

11. TITLE (Include Security Classification)
Estimated UV Clutter Levels at 10-100 Meter Sensor Pixel Resolution Extrapolated from Recent Polar Bear Measurements

12. PERSONAL AUTHOR(S)
M. Wohlers*, R. Huguenin*, M. Weinberg*, R. Huffman, R. Eastes, F. Delgreco

13a. TYPE OF REPORT	13b. TIME COVERED	14. DATE OF REPORT (Year, Month, Day)	15. PAGE COUNT
Reprint	FROM ____ TO ____	1989 7 August 1989	10

16. SUPPLEMENTARY NOTATION
*Aerodyne Research, Inc., Billerica, MA 01821 - ~~Reprinted from SPIE - The International Society for Optical Engineering, Paper No. 1158-03~~

17. COSATI CODES		
FIELD	GROUP	SUB-GROUP

18. SUBJECT TERMS (Continue on reverse if necessary and identify by block number)
Ultraviolet backgrounds; Spatial structure; Clutter

19. ABSTRACT (Continue on reverse if necessary and identify by block number)

There is a continuing need for information about the earth background clutter at ultraviolet wavelengths. This paper describes the methodology and the results obtained at 1304 Å wavelength from an analysis of the AFGL Polar Bear experiment. The basic measurement equipment provided data of a spatial resolution of 20 km over a large portion of the earth. The instrumentation also provided sampled outputs as the footprint scanned along the measurement track. The combination of the fine scanning and large area coverage provided opportunity for a spatial power spectral analysis that in turn provided a means for extrapolation to finer-spatial scale; a companion paper discusses the physical basis for this extrapolation.

20. DISTRIBUTION / AVAILABILITY OF ABSTRACT ☐ UNCLASSIFIED/UNLIMITED ☒ SAME AS RPT. ☐ DTIC USERS	21. ABSTRACT SECURITY CLASSIFICATION Unclassified
22a. NAME OF RESPONSIBLE INDIVIDUAL Francis Delgreco	22b. TELEPHONE (Include Area Code) (617) 377-4758 22c. OFFICE SYMBOL LIU

DD FORM 1473, 84 MAR — 83 APR edition may be used until exhausted. All other editions are obsolete.

SECURITY CLASSIFICATION OF THIS PAGE
Unclassified

89 8 16 027

GL-TR-89-0191

1158-03

Estimated UV clutter levels at 10-100 meter sensor pixel resolution extrapolated from recent Polar Bear measurements

M. Wohlers, R. Huguenin, and M. Weinberg

Aerodyne Research, Inc.
Billerica, MA 01821

and

R. Huffman, R. Eastes, and F. Delgreco
Air Force Geophysics Laboratory, Hanscom AFB, MA 01731

ABSTRACT

There is continuing need for information about the earth background clutter at ultraviolet wavelengths. This paper describes the methodology and the results obtained at 1304 Å wavelength from an analysis of the AFGL Polar Bear experiment. The basic measurement equipment provided data of a spatial resolution of 20 km over a large portion of the earth. The instrumentation also provided sampled outputs as the footprint scanned along the measurement track. The combination of the fine scanning and large area coverage provided opportunity for a spatial power spectral analysis that in turn provided a means for extrapolation to finer-spatial scale; a companion paper discusses the physical basis for this extrapolation.

1. INTRODUCTION

There is continuing need for information about the earth background at ultraviolet wavelengths. There is currently little or no experimental data from which we can infer the spatial variability of ultraviolet earth backgrounds at spatial scales below 1 km. While it is evident that new flight experiments will be required to obtain this needed background data, design of the new experiments will require some knowledge of the background radiance properties at the scales that will be measured. Clutter irradiances at the desired scales are needed to insure that the sensor design includes an adequate optical system, detection response, and measurement scheme.

Recognizing this apparent dilemma, we examined the feasibility of extracting finer scale spatial clutter characteristics from existing UV backgrounds data. UV backgrounds measurement programs were examined, and a significant opportunity to extract the desired information from Polar BEAR/AIRS imager data was discovered. Because of the unique measurement sequence employed in the experiment, the potential existed for extracting clutter information at spatial scales as fine as 45 meters. The significance of this possibility is increased by the fact that the Polar Bear/AIRS Imager is currently operational. If feasibility were demonstrated, the experiment could be programmed to collect additional background data within desired latitudinal regions and at desired points within the diurnal and seasonal cycles. In addition, the experiment is highly flexible with respect to wavelength coverage, so that data could be collected at specified wavelengths to potentially identify phenomenology that may be controlling the fine scale clutter.

With this high potential payoff, a program was undertaken to assess the feasibility of extracting fine-scale spatial clutter information from the Polar BEAR/AIRS Imager data.

The AIRS UV Imager has been measuring aurora and airglow data from a nearly circular, non-sun synchronous, polar, 1000 km elevation orbit since December 1986. The instrument is mounted in an earth nadir-viewing direction on the Polar BEAR Satellite, a Navy Transit class satellite that is a 3-axis passively stabilized platform with a momentum wheel.

The instrument has significant measurement versatility. The sensor can operate in either a multispectral imaging, nadir spectroscopy, or multispectral nadir photometry mode, selectable by ground command. Regional coverage is also selectable, determined by the positions of receiving stations and operational commands. Three fixed ground receiving stations are located in Greenland, Norway, and Fort Churchill, and there is also a transportable receiving station that can be positioned where needed to access a desired orbit. Measurements are generally made north of 45°N due to power constraints. Low altitude data can be collected by adjusting the latitude of operation.

It is the photometer mode data that provides the potential for extracting fine-scale spatial clutter information. In the photometer mode the AIRS UV Imager is in a fixed nadir viewing orientation. The sensor's field-of-view (5 km across track x 20 km along track IFOV) moves along the ground track at a rate of 6.37 km s^{-1}. Measurements are made with an integration period of 6.8330 ms, during which the IFOV slides ~43.5 meters along the ground track. Over a cycle time of 2.9987 s a series of 326 measurements are made, and these are summed in the conventional processing scheme to yield resultant integrated 5 km x 20 km pixel radiances.

This paper describes the methodology and the results obtained at 1304Å wavelength from an analysis of the AFGL Polar Bear experiment. The basic measurement equipment provided data of a spatial resolution of 20 km over a large portion of the earth. The instrumentation also provided sampled outputs as the footprint scanned along the measurement track. The combination of the fine scanning and large area coverage provided opportunity for a spatial power spectral analysis that in turn provided a means for extrapolation to finer spatial scale; a companion paper discusses the physical basis for this extrapolation.

2. RELATIONSHIP OF MEASURED POLAR BEAR DATA TO SPATIAL CLUTTER SPECTRA

The Polar Bear Photometer mode data was collected with an equivalent ground footprint of 5 x 20 km that was scanned along the nadir projection of the satellite trajectory. The detector output at time to can be modeled as I(to) where

$$I(to) = \frac{K}{\Delta T} \int_{to-\Delta T}^{to} \left[\int\int L_B(x,y)\, W(x-v_x t,y)\, dxdy \right] dt$$

where

L_B is the background radiance level

ΔT is the integration time for the measurement

K is the instrument calibration constant

and

$W_{(x,y)}$ is the spatial convolution of the instrument point spread function with the 5 x 20 km rectangular footprint of the sensor.

The spatial variability of the background radiances L_B is traditionally characterized by a spatial Power Spectral Density $S_B(W_x,W_x)$. One of the great utilities of this characterization is the fact that the mean-squared value of the variation of the measured signal in any pixel of size ℓ_x by ℓ_y can be obtained from S_B via the integration

$$\varepsilon\{|J|^2\} = \frac{(\ell_x\ell_y)^2}{(2\pi)^4} \iint S_B(w_x,w_y) \left[\frac{\sin \frac{w_x\ell_x}{2}}{\frac{w_x\ell_y}{2}} \; \frac{\sin \frac{w_y\ell_y}{2}}{\frac{w_y\ell_y}{2}} \cdot e^{-r_b^2 (w_x^2 + w_y^2)} \right]^2 dw_x dw_y$$

where

$\varepsilon(\bullet)$ is the expected value of $(\bullet)$

J is the radiant intensity (watts/sr) observed by a sensor with pixel size ℓ_x by ℓ_y

S_B is the power spectral density in $\frac{(w \mid cm^2 \mid sr)^2}{(1 \mid cm)^2}$

w_x, w_y are the spatial frequency variables

and we have assumed that the optical transfer function of the sensor can be modeled by a Gausian point spread function with radius r_b.

Note that in the situation where $\ell_y \to o$ this relationship can be approximated by

$$\varepsilon\{|J|^2\} = (\ell_x\ell_y)^4 \quad \frac{1}{(2\pi)^4} \iint S_B(w_x,w_y)\, dw_x dw_y$$

or the variance of the radiant intensity is a function only of the pixel size.

This relationship suggests that the power spectral density characterizing the background can be obtained by Fourier transforming the measured Polar Bear output. Since this data is in discrete form, i.e., values at the end of each sample interval ΔT, one utilizes the discrete Fourier transform

$$F\,[I(n\Delta T)] = F\left(\frac{k}{N}\frac{2\pi}{\Delta T}\right) = \sum_{n=1}^{N} I(n\Delta T)\; e^{-j(n\Delta T)\left(\frac{k}{N}\frac{2\pi}{\Delta T}\right)}$$

where

k is the discrete Fourier frequency index, and

N is the total number of time samples transformed.

One can then obtain the following relationship between this transform of the data and S_B

$$\varepsilon\{\,|\,F\,[I(n\Delta T]\,|\,^2\} = \frac{K^2}{(2\pi)^4} \int\!\!\int S_B(w_x,w_y)\,\left[\frac{\sin\frac{w_x\ell_x}{2}}{\frac{w_x\ell_x}{2}}\;\frac{\sin\frac{w_y\ell_y}{2}}{\frac{w_y\ell_y}{2}}\right. \cdot$$

$$e^{-r_b^2\,(w_x^{\,2}+w_y^{\,2})}\;\sin\frac{(w_x\,v_x\,\frac{\Delta T}{2})}{w_x\,v_x\,\frac{\Delta T}{2}} \cdot$$

$$\left.\frac{\sin N(\frac{k\pi}{N} - \frac{w_x\,v_x\,\Delta T}{2})}{\sin(\frac{k\pi}{N} - \frac{w_x\,v_x\,\Delta T}{2})}\right]^2 dw_x dw_y$$

where the data calibration factor K has units of output intensity (perhaps counts in a photomultipler) for a measurement pixel of dimensions ℓ_x,ℓ_y, per radiance level (w | cm^2 | sr).

It is clear that the Fourier transform of the measured data does not yield the desired background power spectral density directly but that there is an integrated weighting due to the nature of the measurement pixel size ℓ_x, ℓ_y, its optical point spread function, a processing function which depends on the number of samples used in the discrete transform, and the net linear motion of the footprint ($V_x\Delta T$) that occurs during the sampling time ΔT. In certain cases this integrated weighting can be deconvolved to obtain the desired S_B. For example, if S_B can be written as a function of w_x times a function of w_y, i.e., $S_B(w_x,w_y) = f(w_x)\,f(w_y)$ then as the number of the Fourier samples is increased and the footprint motion decreased so that $NV_x\Delta T$ grows large then

$$\varepsilon\{\,|\,F[I(n\Delta T]\,|\,^2\} \sim \sqrt{S_B(w_x)}\;\frac{\sin\frac{w_x\ell_x}{2}}{\frac{w_x\ell_x}{2}}\;e^{-r_b^2 w_x^{\,2}}\;\Big|\,w_x = \frac{2\pi k}{NV_x\Delta T}$$

Thus the desired PSD S_B can be obtained if the optical parameters of the sensor are known, i.e., the footprint ℓ_x and blur circle radius r_b.

A potential equally difficult problem involved with the extraction of the background PSD from the measured data is the noise associated in the sensor. In the Polar Bear analysis being discussed the limiting noise is the shot noise or counting noise associated with the limited number of optical photons available in the receiver during the sample time ΔT. The contribution of the shot noise to the Fourier transform of the measured data can be assessed by assuming that the probability of the number of counts n_i in the i^{th} sample period can be described by a Poisson distribution with probability density

$$\text{Prob}\left\{n_i = k\right\} = e^{-M} \frac{M^k}{k!}$$

where M is the average number of counts in the sample period, note that the RMS value of the counts in then $\sqrt{M}$. The expected value of the Fourier transform of a sequence of N such samples satisfying this statistical law is then determined by

$$\varepsilon\{\,|\,F[n_i]\,|^{\,2}\} = \begin{array}{l} N^2M^2 + NM \text{ at zero frequency} \\ NM \text{ at all other frequencies} \end{array}$$

Analysis of a sequence of approximately 3 seconds of Polar Bear data (with M = 256) resulted in a normalized Fourier transform spectrum shown in Figure 1. The plot is of the

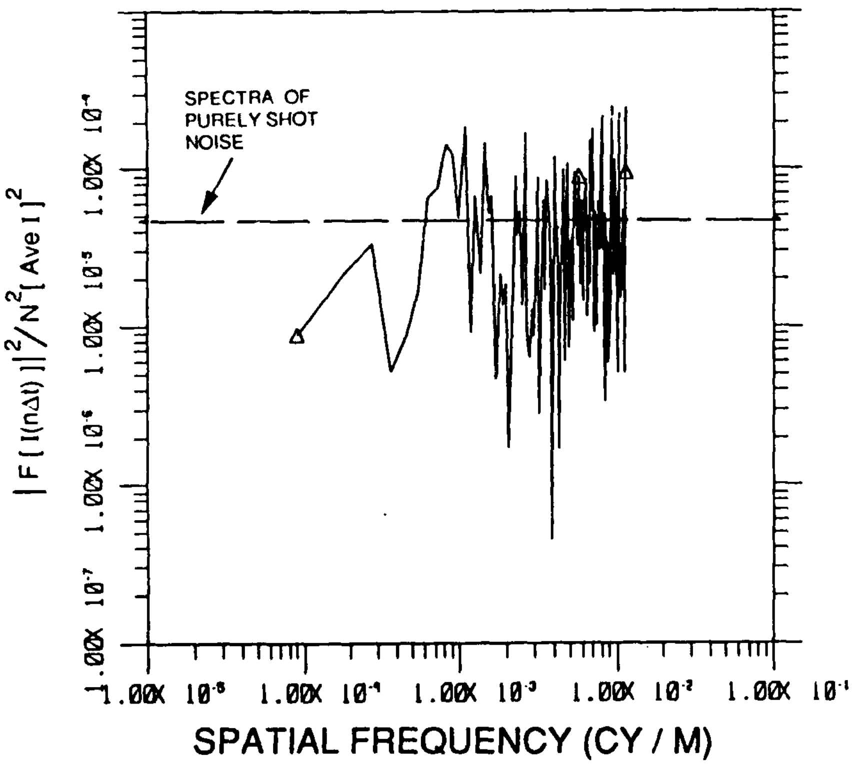

Figure 1. Spectral Analysis of a Three Second Segment of Polar Bear Photometer Data

$$\frac{|F[I(n\Delta T)]|^2}{N^2(\text{Ave } I)^2}$$

i.e., the square of the transform divided by the square of the product of N and the average value of the measured data. On the same curve, the normalized level of the Fourier spectrum of a purely shot noise process is also shown. It is clear that the measured data is dominated by the shot noise in the observation. The likelihood of extracting any useful information from such a sample is very small. Fortunately as larger sequences of data were analyzed one does obtain useful information at lower spatial frequency, for example Figure 2 shows the Fourier spectra of a sequence of $N = 32768$ points (approximately 300 seconds of data) which shows the shot noise level and the component of the measurement due to the spatial variation of the background that emerges at lower frequencies.

3. <u>Extrapolation of Low Frequency Spectral Data</u>

The procedure that has been evolved to extract the background radiance PSD, S_B, from the Fourier spectrum of the measured data is based on an assumed form for S_B namely that

$$S_B(w_x, w_y) = \begin{cases} A, & \text{for } \sqrt{w_x^2 + w_y^2} < \dfrac{2\pi}{L} \\[2ex] \dfrac{A}{\sqrt{\dfrac{w_x^2 + w_y^2}{(2\pi/L)^2}}^{\,\beta+1}}, & \text{for } \sqrt{w_x^2 + w_y^2} > \dfrac{2\pi}{L} \end{cases}$$

One can then demonstrate that if the discrete Fourier transform variable k is such that

$$\frac{2\pi}{\ell_x} \gg k\frac{2\pi}{NV_x\Delta T} \gg \frac{2\pi}{L} \quad ,$$

$$\frac{k2\pi}{NV_x\Delta T} \cdot r_b \ll 1 \quad ,$$

$$\frac{k}{N} \ll 1 \quad ,$$

and

$$\ell_x > \ell_y$$

then the fourier spectrum of the measured data can be approximated as

$$\varepsilon\{|F[I(n\Delta T)]|^2\} \approx \frac{K^2}{(2\pi)^2}\,\frac{A}{(V_x\,\Delta T)^2}\left(\frac{NV_x\Delta T}{L}\right)^{\beta+1}\int_{-\infty}^{\infty}\frac{1}{(1+z^2)^{\beta+1/2}}\,dz\,\frac{1}{k^\beta}$$

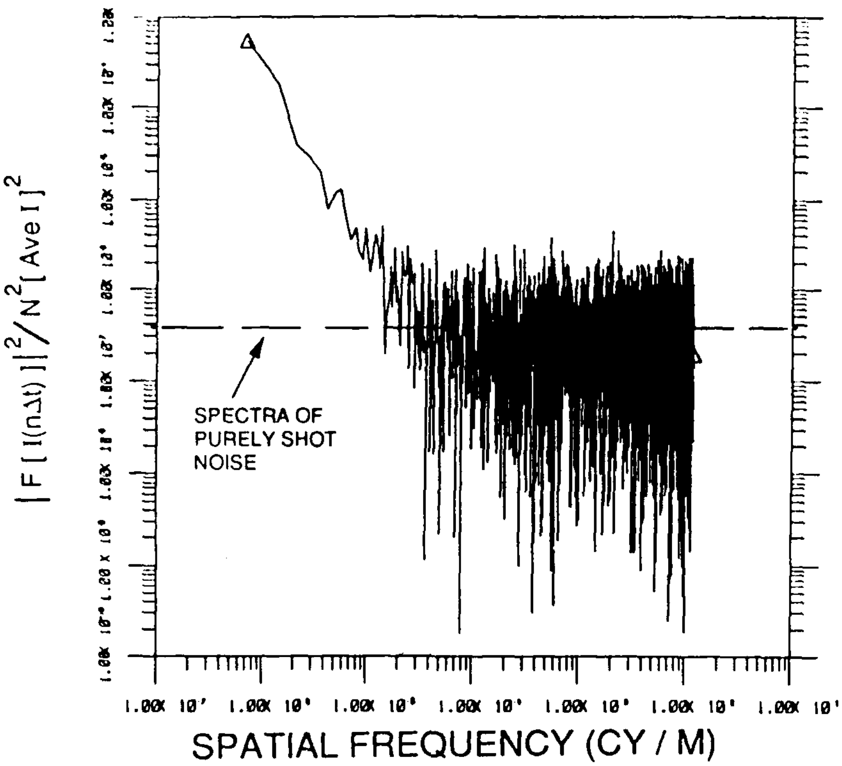

Figure 2. Spectral Analysis of Three Hundred Second Segment of Polar Bear Photometer Data

Moreover, in a footprint $\hat{\ell}_x$ such that $\hat{\ell}_x << L$, the variance of the measured data can be approximated by

$$\varepsilon\{ \mid \hat{I}(n\Delta T) - \bar{\hat{I}} \mid ^2\} = \frac{\hat{K}^2 A}{2\pi L^2} \quad \frac{\beta+1}{2(\beta-1)}$$

where $\hat{K}$ is the instrument calibration constant for a footprint $\hat{\ell}_x$; note that $\hat{K} = \hat{\ell}_x/\ell_x K$

These two expressions suggest the following procedure for obtaining the desired constants (β, A, and L), defining the background variance S_B, from the measured spectra

1) in a region of the measurement spectra not dominated by shot noise establish a best fit of the function

$$S_B = \frac{\text{constant}}{k^\beta}$$

Thus establishing β and one relationship between A and L given by

$$\mid F_o \mid ^2 = \frac{K^2}{(2\pi)^2} \frac{A}{(V_x \Delta T)^2} \left(\frac{NV_x \Delta T}{L}\right)^{\beta+1} \int_{-\infty}^{\infty} \frac{1}{(1 + z^2)^{\beta+1/2}} dz \frac{1}{k_o^\beta}$$

where $|F_o|^2$ is some point on the spectrum corresponding to the variable k_o where the spectra and the fitting function coincide (assumed to be at as large a value of k_o as possible but below the region dominated by shot noise).

2) utilize the approximate expression for the variance to establish a second relationship between A and L. These two relationships can be combined to obtain expressions for L and A given by

$$\left(\frac{L}{V_x \Delta T}\right)^{\beta-1} = \left(\frac{\ell_x}{\hat{\ell}_x}\right)^2 \frac{N^{\beta+1}}{k_o^{\beta}} \left[\int_{-\infty}^{\infty} \frac{1}{(1+z^2)^{\beta+1/2}}\, dz\right] \left(\frac{\beta-1}{\beta+1}\right) \frac{\varepsilon\{|I(n\Delta T) - \bar{I}|^2\} - \bar{I}}{[|F_o|^2 - N\bar{I}]}$$

and

$$A = [\varepsilon\{|\hat{I}(n\Delta T) - \bar{\hat{I}}|^2\} - \bar{\hat{I}}]\, \frac{4\pi\, (\beta-1)\, L^2}{\hat{K}^2 (\beta+1)}$$

where $\hat{I}$ is the equivalent measured data in a footprint $\hat{\ell}_x$ corresponding to

$$k_o = \frac{N\, V_x \Delta T}{\hat{\ell}_x}$$

Note that the measured Polar Bear data was repeatedly sampled at time steps corresponding to incremental motion of the sensor footprint ($V_x \Delta t$). Thus if one wanted an $\hat{\ell}_x$ corresponding to "M" multiples of the basic Polar Bear footprint (ℓ_x) then samples of data corresponding to the $\hat{\ell}_x$ footprint can be obtained by the indexed sum

$$\hat{I} = I(n) + I(n + k) = I(n + 2k) + \text{---} + I[n + (M - 1)k]$$

of the basic Polar output data which has k data points within each footprint, i.e. $k\, V_x \Delta T = \ell_x$. Note also that these expressions have been corrected for the shot noise contribution to both the Fourier spectra of the measured data and the variance of the measured data. In addition the constant $\hat{K}$ must be the equivalent instrument scale factor for the footprint size $\hat{\ell}_x$ ($\hat{K}$ = MK for the above situation).

These results can also be applied directly to obtain a measure of the RMS level of the background clutter since

$$\sigma_{\ell_x \ell_y} = \text{RMS of radiant intensity} = \ell_x \ell_y \frac{\sqrt{\varepsilon\{|\hat{I} - \bar{\hat{I}}|^2\} - \bar{\hat{I}}}}{\hat{K}}$$

if ℓ_x and ℓ_y are both much less than the model constant L. In particular the RMS level of the background radiance is given by

$$\frac{\sigma}{\ell_x \ell_y} = \frac{\sqrt{\varepsilon\{|\hat{I} - \bar{\hat{I}}|^2\} - \bar{\hat{I}}}}{\hat{K}} \quad \frac{w}{cm^2\text{-}sr}$$

4. Example Results of the Polar Bear Data Analysis

Using the procedure developed in Section 3, a series of Polar Bear photometer mode data measured at 1304 Å was analyzed to obtain estimates of the background clutter power spectral density. A typical curve fitting to the measured spectra obtained for N = 32,768 data pounds or approximately 300 seconds is shown in Figure 3 from which one obtains the slope

$$\beta \approx 1.97$$

and the fitted point $k_o = 24$ (corresponding to a spatial frequency of 1.65×10^{-5} cycles/meter and a footprint size ℓ_x of 60 km) for $|F_o|^2 = 1.316 \times 10^7$. For the same sequence of data $N^2 I^2 = 0.329 \times 10^{13}$. The instrument calibration constant K was determined to be

$$6.06 \times 10^{10} \ \frac{\text{counts}}{\text{w/cm}^2\text{-sr}}$$

The variance of the measured data in the 60 km equivalent footprint, i.e., $\mathcal{E}\{|\hat{I} - \bar{\hat{I}}|^2\}$ was obtained as $(14.5)^2$ counts^2 and the mean number of counts $\hat{I} = 1.66$. The value of L obtained from the corresponding expressions in Section 3 was 2×10^3 km which for the sake of physical reference is approximately one twentieth the circumference of the earth.

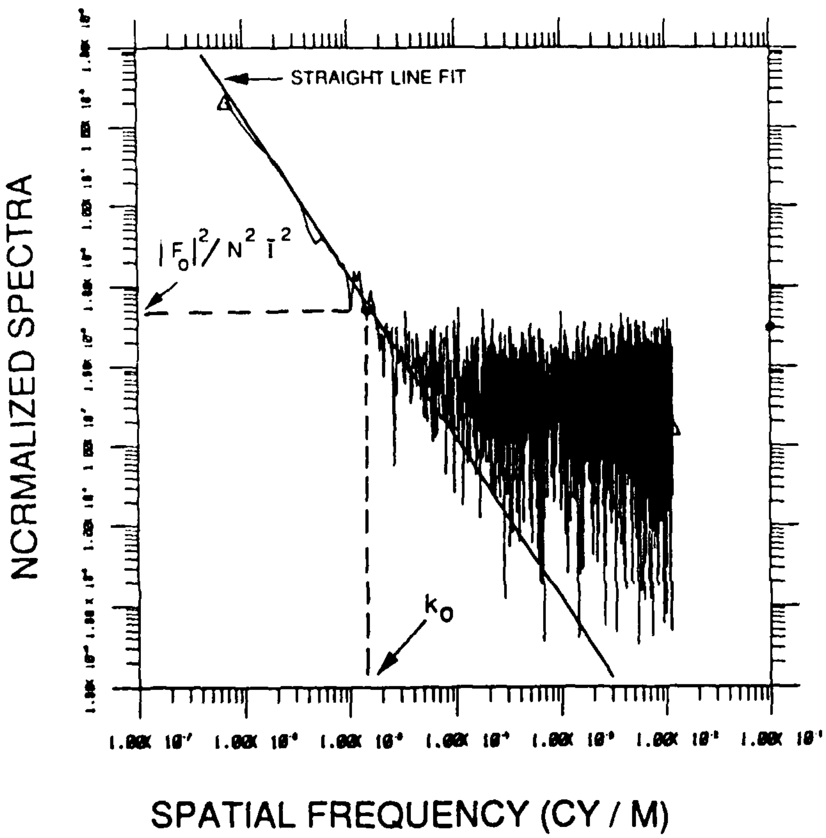

Figure 3. Example of the Data Fitting Procedure for Polar Bear Data (Summer, Mid Day Observations at 300 Seconds at Latitude 60 - 75° North)

Similar analysis was conducted at different latitudes with results shown in Figure 4 for the slope β, the RMS value of the spectral radiance, and the ratio of the RMS to mean radiance. Note that the nominal spectral half width of the measured instrument was 35 Å which allowed the results to be quoted as spectral radiance.

The resulting background radiance levels and the corresponding relationship for the RMS level of the clutter in the footprint ($\sigma \sim$(constant) $\ell_x \ell_y$) was justified for the extrapolation procedure applied to this data, i.e. the approximations employed in the analysis are met by the data. Thus one has a means for estimating clutter at finer spatial scale than the Polar Bear footprint. However, since the measured data at finer scales is contaminated by counting noise one can not be sure that the extrapolation procedure to scales such as 10-100 meters is valid, i.e., there may be physical processes that enter at the scale which invalidate the fractal nature of the phenomena. The discussion of the companion paper provides some justification for the extrapolation into their region based upon phenomenological considerations. It is clear, however, that direct measurements at these scale lengths are necessary in order to establish the validity of these conclusions.

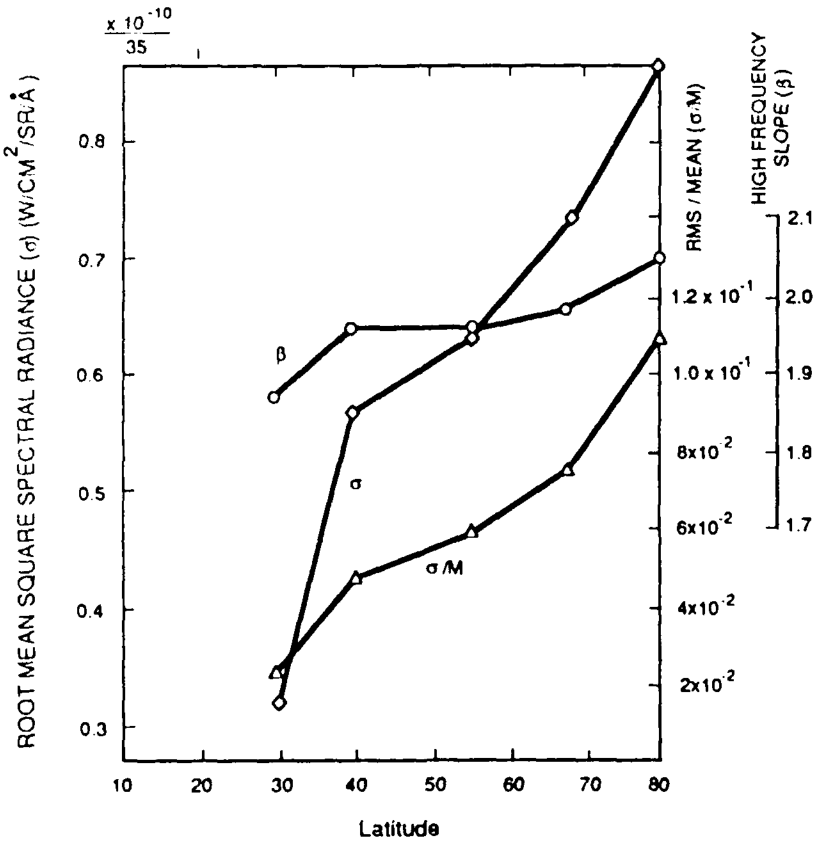

Figure 4. Polar Bear Measured Spatial Radiance Clutter Levels of Sunlit Earth Background at 1304 Å